Claims

1. A method for detecting the gap of a liquid-crystal panel, this method comprising the steps of:

arranging the liquid-crystal panel so that a polarized incident light is incident almost parallel to the normal to the liquid-crystal panel and the reflected light from the liquid-crystal panel is received by a received light quantity detection device via an analyzer having a transmission axis almost perpendicular to the polarization direction of the incident light;

rotating the direction of polarization of the incident light with respect to the liquid-crystal panel and detecting the extinction angle at which the intensity of light detected by the received light quantity detection device reaches minimum; and

detecting the gap of the liquid-crystal panel based on the detected extinction angle.

2. The method for detecting the gap of a liquid-crystal panel as described in claim 1, wherein the direction of polarization of the incident light on the liquid-crystal panel and the panel are rotated relative to each other by rotating the liquid-crystal panel about the axis almost parallel to the direction of incidence of the incident light as a center.

3. The method for detecting the gap of a liquid-crystal panel as described in claim 1, wherein gap d of the liquid-crystal panel is detected by the following equations by using the detected extinction angle ϕ_{app}:

$$\tan 2\varphi\,\mathrm{app} = \tan 2\left(\varphi\,\mathrm{app} + \frac{\pi}{2}\right) = \varphi\,\frac{\tan X}{X}$$

$$X = \sqrt{\varphi^2 + \beta^2} \qquad \beta = \frac{\pi \Delta n\, d}{\lambda}$$

$$\Delta n = \frac{n_e \cdot n_o}{\sqrt{n_o^2 + (n_e^2 - n_o^2)\sin\theta}} - n_o$$

where λ is the wavelength of the incident light, ϕ is the twisting angle of the liquid-crystal panel, n_o is the refractive index of the liquid crystal material with respect to

ordinary light, n_e is the refractive index of the liquid crystal material with respect to extraordinary light, Δn is the refractive index anisotropy of the liquid-crystal panel, θ is the tilt angle of the liquid-crystal panel.

4. A method for detecting the gap of a liquid-crystal panel, this method comprising the steps of:

arranging the liquid-crystal panel so that a polarized incident light falls almost parallel to the normal to the liquid-crystal panel and the reflected light from the liquid-crystal panel is received by a received light quantity detection device via an analyzer;

detecting a first output signal from the received light quantity detection device in a state in which the transmission axis of the analyzer is arranged so as to be almost parallel to the polarization direction of the incident light;

detecting a second output signal from the received light quantity detection device in a state in which the transmission axis of the analyzer is arranged so as to be almost perpendicular to the polarization direction of the incident light; and

detecting the gap of the liquid-crystal panel based on the first and second output signals.

5. The method for detecting the gap of a liquid-crystal panel as described in claim 4, wherein gap d of the liquid-crystal panel is detected by the following equations by using the first output signal R_x and the second output signal R_y:

$$R_x = \cos^2 \beta_{eff} + \cos^2 2(\phi_{app} + \alpha^{in}) \cdot \sin^2 \beta_{eff}$$

$$R_y = \sin^2 2(\phi_{app} + \alpha^{in}) \cdot \sin^2 \beta_{eff}$$

$$\cos \beta_{eff} = \cos^2 X + (\varphi^2 - \beta^2) \frac{\sin^2 X}{X^2}$$

$$\cos 2\varphi_{app} \cdot \sin \beta_{eff} = 2\beta \frac{\sin X \cdot \cos X}{X}$$

$$\sin 2\varphi_{app} \cdot \sin \beta_{eff} = 2\varphi\beta \frac{\sin^2 X}{X^2}$$

$$\beta_{eff} = \frac{2\pi \cdot \Delta n_{eff} \cdot d}{\lambda}$$

$$\tan 2\varphi_{app} = \varphi \frac{\tan X}{X}$$

$$X = \sqrt{\varphi^2 + \beta^2} \qquad \beta = \frac{\pi \Delta n\, d}{\lambda}$$

$$\Delta n = \frac{n_e \cdot n_o}{\sqrt{n_o^2 + (n_e^2 - n_o^2)\sin\theta}} - n_o$$

where λ is the wavelength of the incident light, ϕ is the twisting angle of the liquid-crystal panel, n_o is the refractive index of the liquid crystal material with respect to ordinary light, n_e is the refractive index of the liquid crystal material with respect to extraordinary light, Δn is the refractive index anisotropy of the liquid-crystal panel, θ is the tilt angle of the liquid-crystal panel, and α^{in} is the angle between the polarization direction of the incident light and the orientation direction of liquid crystal molecules at the substrate on the incident light side.

6. The method for detecting the gap of a liquid-crystal panel as described in claim 4, further comprising a step of detecting a third output signal from the received light quantity detection device in a state in which the transmission axis of the analyzer is located on a bisector of the direction almost parallel to the polarization direction of the incident light and the direction almost perpendicular thereto, and in the step of detecting the gap of the liquid-crystal panel, the gap of the liquid-crystal panel is detected based on the first, second, and third output signals.

7. The method for detecting the gap of a liquid-crystal panel as described in claim 6, wherein gap d of the liquid-crystal panel is detected by the following equations by using the first output signal R_x, the second output signal R_y, and the third output signal R_{xy}:

$$R_{xy} = \frac{1}{2}[1 + \sin\beta_{eff} \cdot \sin 4(\varphi_{app} + \alpha^{in})]$$

$$R_x = \cos^2 \beta_{eff} + \cos^2 2(\phi_{app} + \alpha^{in}) \cdot \sin^2 \beta_{eff}$$

$$R_y = \sin^2 2(\phi_{app} + \alpha^{in}) \cdot \sin^2 \beta_{eff}$$

$$\cos\beta_{eff} = \cos^2 X + (\varphi^2 - \beta^2)\frac{\sin^2 X}{X^2}$$

$$\cos 2\varphi_{app} \cdot \sin\beta_{eff} = 2\beta\frac{\sin X \cdot \cos X}{X}$$

$$\sin 2\varphi_{app} \cdot \sin\beta_{eff} = 2\varphi\beta\frac{\sin^2 X}{X^2}$$

$$\beta_{eff} = \frac{2\pi \cdot \Delta n_{eff} \cdot d}{\lambda}$$

$$\tan 2\varphi_{app} = \varphi\frac{\tan X}{X}$$

$$X = \sqrt{\varphi^2 + \beta^2} \qquad \beta = \frac{\pi\Delta n\, d}{\lambda}$$

$$\Delta n = \frac{n_e \cdot n_o}{\sqrt{n_o^2 + (n_e^2 - n_o^2)\sin\theta}} - n_o$$

where λ is the wavelength of the incident light, ϕ is the twisting angle of the liquid-crystal panel, n_o is the refractive index of the liquid crystal material with respect to ordinary light, n_e is the refractive index of the liquid crystal material with respect to extraordinary light, Δn is the refractive index anisotropy of the liquid-crystal panel, θ is the tilt angle of the liquid-crystal panel, and α^{in} is the angle between the polarization direction of the incident light and the orientation direction of liquid crystal molecules at the substrate on the incident light side.

8. The method for detecting the gap of a liquid-crystal panel as described in claim 4, wherein in the step of detecting the first output signal and in the step of detecting the second output signal, the detection is conducted in at least two different rotation positions obtained by rotating about an axis almost parallel to the direction of incidence of the incident light on the liquid-crystal panel as a center and the gap of the liquid-crystal panel is detected based on the output signals detected in each rotation position.

9. The method for detecting the gap of a liquid-crystal panel as described in claim 8, wherein the angles differ by no less than 5^o.

10. The method for detecting the gap of a liquid-crystal panel as described in claim 4, wherein a half-mirror is provided for reflecting the light from the light source, directing it toward the liquid-crystal panel, and transmitting the reflected light from the liquid-crystal panel, and the gap of the liquid-crystal panel is detected based on the first and second output signals and the predetermined noise light quantity and transmissivity of the half-mirror.

11. The method for detecting the gap of a liquid-crystal panel as described in claim 4, wherein a half-mirror is provided for reflecting the light from the light source, directing it toward the liquid-crystal panel, and transmitting the reflected light from the liquid-crystal panel, and the gap of the liquid-crystal panel is detected based on the first and second output signals and the predetermined quantity of the incident light, noise light quantity, and transmissivity of the half-mirror.

12. The method for detecting the gap of a liquid-crystal panel as described in claim 4, further comprising the steps of measuring a fourth output signal representing the noise light quantity, which contains the surface reflected light from the received light quantity detection device as the main component, in a state in which the transmission axis of the analyzer is arranged so as to be almost parallel to the polarization direction of the incident light, and

measuring a fifth output signal representing the noise light quantity, which contains the external light from the received light quantity detection device as the main component, in a state in which the transmission axis of the analyzer is disposed so as to be almost perpendicular to the polarization direction of the incident light, wherein the gap of the liquid-crystal panel is detected based on the first to fifth output signals.

13. A method for detecting the gap of a liquid-crystal panel, this method comprising the steps of:

directing a polarized incident light almost parallel to the normal to the liquid-crystal panel;

directing the reflected light from the liquid-crystal panel into a polarization beam splitter and separating the light with a polarization direction almost parallel to

the polarization direction of the incident light and the light with a polarization direction almost perpendicular to the polarization direction of the incident light,

detecting the quantity of light with a polarization direction almost parallel to the polarization direction of the incident light with a first received light quantity detection device and detecting the quantity of light with a polarization direction almost perpendicular to the polarization direction of the incident light with a second received light quantity detection device; and

detecting the gap of the liquid-crystal panel based on the detection signal of the first received light quantity detection device and the detection signal of the second received light quantity detection device.

14. An apparatus for detecting the gap of a liquid-crystal panel comprising:

a light emission apparatus for causing a polarized incident light to fall almost parallel to the normal to the liquid-crystal panel;

an analyzer for receiving the reflected light from the liquid-crystal panel, the analyzer being arranged so that the transmission axis thereof is almost perpendicular to the polarization direction of the incident light;

a received light quantity detection device for receiving the light that passed the analyzer; and

a processing apparatus, wherein the processing apparatus detects the gap of the liquid-crystal panel based on an extinction angle at which the output signal of the received light quantity detection device reaches minimum when the direction of incidence of the incident light is rotated relative to the transmission axis direction of the analyzer.

15. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 14, wherein the processing apparatus detects the gap of the liquid-crystal panel based on the extinction angle when the liquid-crystal panel is rotated about the axis almost parallel to the direction of incidence of the incident light.

16. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 14, wherein the light emission apparatus comprises a polarizer.

17. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 14, wherein the received light quantity detection device uses a surface-type imaging element.

18. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 14, wherein the light emission apparatus or the received light quantity detection device has a wavelength selection function.

19. An apparatus for detecting the gap of a liquid-crystal panel, comprising:

a light emission apparatus for causing a polarized incident light to fall almost parallel to the normal to the liquid-crystal panel;

an analyzer disposed so as to receive the reflected light from the liquid-crystal panel;

a received light quantity detection device for receiving the light that passed the analyzer; and

a processing apparatus, wherein the processing apparatus detects the gap of the liquid-crystal panel based on a first output signal from the received light quantity detection device in a state in which the analyzer is disposed so that the transmission axis of the analyzer is almost parallel to the polarization direction of the incident light and a second output signal from the received light quantity detection device in a state in which the analyzer is disposed so that the transmission axis of the analyzer is almost perpendicular to the polarization direction of the incident light.

20. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 19, wherein the light emission apparatus comprises a polarizer

21. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 19, wherein the received light quantity detection device uses a surface-type imaging element.

22. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 19, wherein the light emission apparatus or the received light quantity detection device has a wavelength selection function.

23. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 19, wherein the processing apparatus detects the gap of the liquid-crystal panel based on the first output signal and the second output signal in at least two different rotation positions obtained by rotation around an axis almost parallel to the direction of incidence of the incident light onto the liquid-crystal panel.

24. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 19, wherein the processing apparatus detects the gap of the liquid-crystal panel based on the first output signal, the second output signal, a fourth output signal representing the noise light quantity, which contains the surface reflected light from the received light quantity detection device as the main component, in a state in which the transmission axis of the analyzer is disposed so as to be almost parallel to the polarization direction of the incident light, and a fifth output signal representing the noise light quantity, which contains the external light from the received light quantity detection device as the main component, in a state in which the transmission axis of the analyzer is disposed so as to be almost perpendicular to the polarization direction of the incident light.

25. An apparatus for detecting the gap of a liquid-crystal panel, comprising:

a light emission apparatus for causing a polarized incident light to fall almost parallel to the normal to the liquid-crystal panel;

a polarization beam splitter disposed so as to receive the reflected light from the liquid-crystal panel and separating a light having a polarization direction almost parallel to the polarization direction of the incident light and a light having a polarization direction almost perpendicular to the polarization direction of the incident light from the reflected light;

a first received light quantity detection device disposed so as to receive the

light having a polarization direction almost parallel to the polarization direction of the incident light, this light being received from the polarization beam splitter;

a second received light quantity detection device disposed so as to receive the light having a polarization direction almost perpendicular to the polarization direction of the incident light, this light being received from the polarization beam splitter; and

a processing apparatus, wherein the processing apparatus detects the gap of the liquid-crystal panel based on the detection signal of the first received light quantity detection device and the detection signal of the second received light quantity detection device.

26. An apparatus for detecting the gap of a liquid-crystal panel, comprising:

a light emission apparatus for causing a polarized incident light to fall almost parallel to the normal to the liquid-crystal panel;

an analyzer disposed so as to receive the reflected light from the liquid-crystal panel;

a received light quantity detection device for receiving the light that passed the analyzer; and

a processing apparatus, wherein the processing apparatus detects the gap of the liquid-crystal panel based on a first output signal from the received light quantity detection device in a state in which the analyzer is disposed so that the transmission axis of the analyzer is almost parallel to the polarization direction of the incident light, a second output signal from the received light quantity detection device in a state in which the analyzer is disposed so that the transmission axis of the analyzer is almost perpendicular to the polarization direction of the incident light, and a third output signal from the received light quantity detection device in a state in which the analyzer is disposed so that the transmission axis of the analyzer is located on a bisector of the direction almost parallel to the polarization direction of the incident light and the direction almost perpendicular thereto.

27. The apparatus for detecting the gap of a liquid-crystal panel, as described in Claim 26, wherein the light emission apparatus comprises a polarizer.

28. The apparatus for detecting the gap of a liquid-crystal panel, as described in Claim 26, wherein the received light quantity detection device uses a surface-type imaging element.

29. The apparatus for detecting the gap of a liquid-crystal panel as described in Claim 26, wherein the light emission apparatus or the received light quantity detection device has a wavelength selection function.